

Astrotech 21 Workshop Proceedings:
Optical Systems Technology for Space Astrophysics in the 21st Century

SECTION IV (Cont'd)
WORKSHOP PANEL REPORT:

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5. OPTICAL SYSTEMS INTEGRATED MODELING

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INTRODUCTION

An integrated modeling capability that provides the tools by which entire optical systems and instruments can be simulated and optimized is a key technology development, applicable to all mission classes, especially astrophysics. Many of the future missions require optical systems that are physically much larger than anything flown before and yet must retain the characteristic sub-micron diffraction limited wavefront accuracy of their smaller precursors. It is no longer feasible to follow the path of "cut and test" development; the sheer scale of these systems precludes many of the older techniques that rely upon ground evaluation of full size engineering units. The ability to accurately model (by computer) and optimize the entire flight system's integrated structural, thermal, and dynamic characteristics is essential.

Two distinct integrated modeling capabilities are required. These are an *initial design capability* and a *detailed design and optimization system*. The content of an initial design package is shown in Figure 41. It would be a modular, workstation based code which allows preliminary integrated system analysis and trade studies to be carried out quickly by a single engineer or a small design team. A simple concept for a detailed design and optimization system is shown in Figure 42. This is a linkage or interface architecture that allows efficient interchange of information between existing large specialized optical, control, thermal, and structural design codes. The computing environment would be a network of large mainframe machines and its users would be project level design teams. More advanced concepts for detailed design systems would support interaction between modules and automated optimization of the entire system.

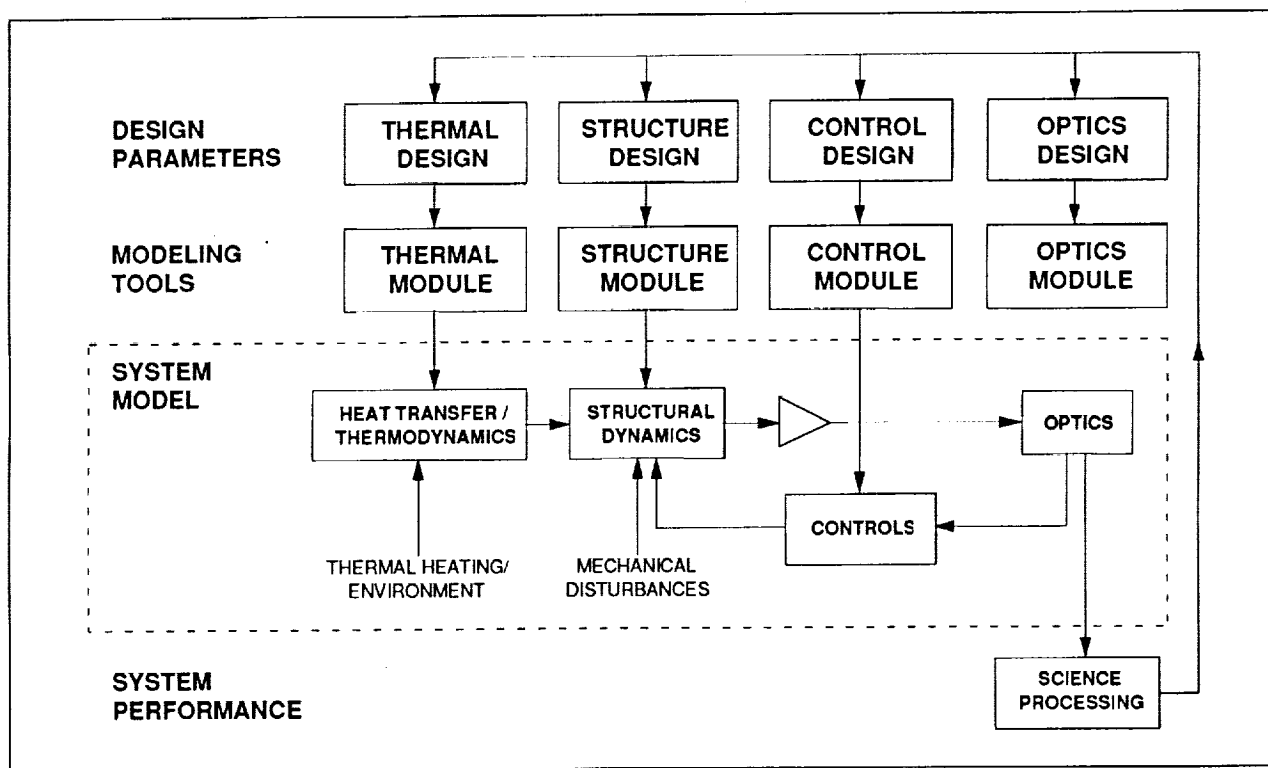


Figure 41. Integrated Modeling - Concept for an initial design capability that allows preliminary integrated system design and analysis. Implementation as a modular workstation-based code would allow a single engineer or a small design team to carry out system design and optimization.

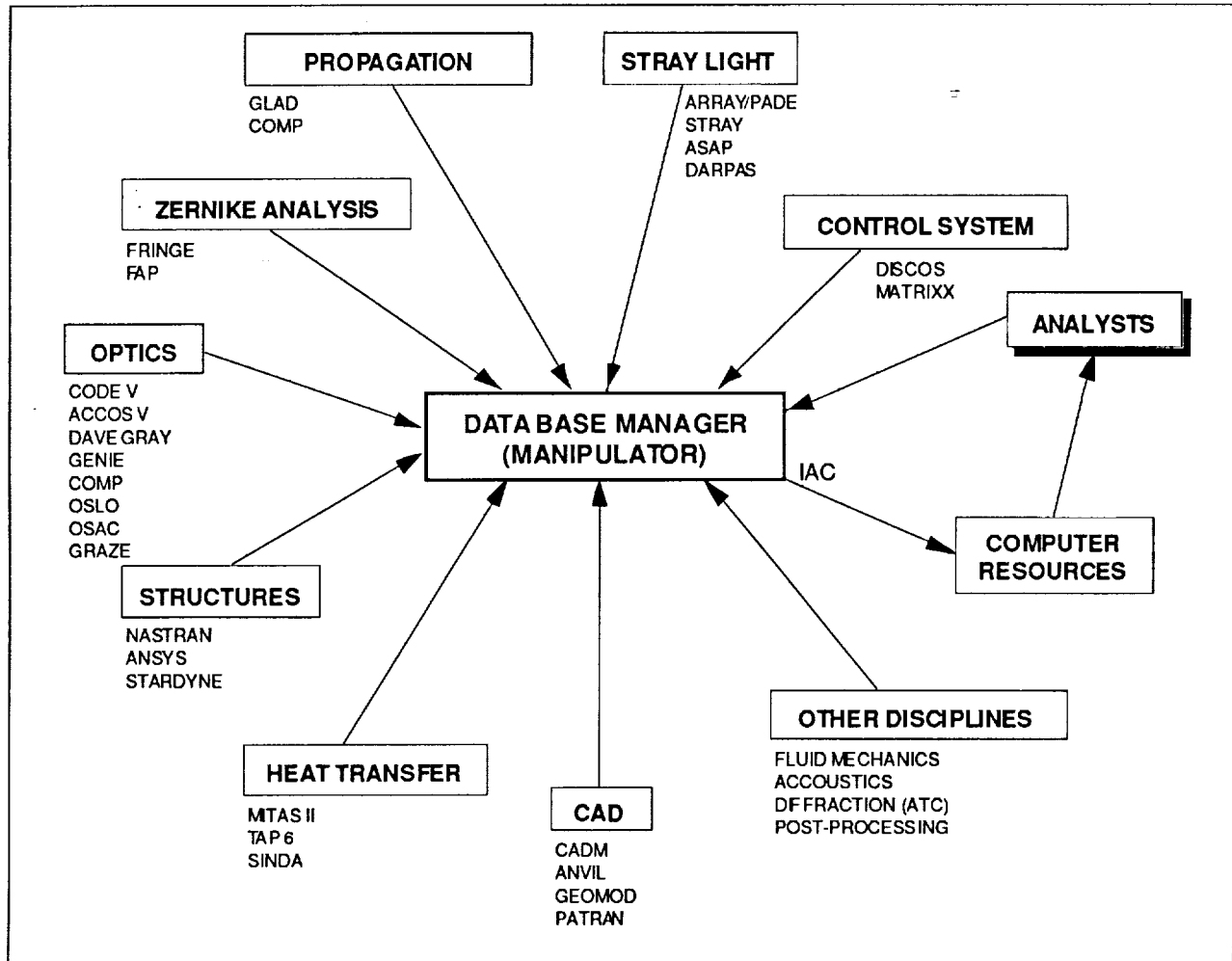


Figure 42. Integrated System Modeling (ISM) Concept

Since it will be difficult, perhaps impossible, to fully test future large space optical systems on the ground, the system designers and integrators will rely heavily on model predictions without the benefit of direct corroborating data. Confidence in the accuracy of the models must be high and this can only be achieved through validation against small scale experiments and existing flight performance

data. Validation is a critical part of the integrated modeling effort.

In order to focus the NASA component of the integrated modeling technology effort, the panel adopted the set of guiding principles that are summarized in Table 36. Table 37 summarizes the recommendations of the panel with respect to technology development in modeling.

Table 36. Principles for Directed Technology Development in Integrated Modeling

1	NASA should undertake the development of an integrated modeling capability that supports <u>initial design</u> .
2	NASA should not attempt to develop its own universal <u>detailed design and optimization system</u> . Instead, NASA should support the development of an "industry standard" language for interpackage communication that includes networking and documentation. The goal is to achieve maximum leverage from the substantial investment and experience that can be obtained from existing specialized design software.
3	Ongoing validation of the accuracy of component and system level performance predictions is critical.
4	NASA should also obtain leverage from the strong modeling expertise that exists in academic and industrial laboratories.

Table 37. Recommended Integrated Modeling Technologies for Astrophysics Missions : 1992-2010

TECHNOLOGY AREA	OBJECTIVES	REQUIRED DEVELOPMENT	MISSIONS IMPACTED	TECH. FREEZE DATE
Integrated Package for Initial Design	Software Tool that Allows Preliminary Design, Characterization, and Optimization of Optical Systems.	IMOS Software Package	All	'92 - '08
Interface Development for Detailed Optimization	Develop and Maintain an End to End Simulation Capability, Integrating Optical, Structural Control, and Environmental Design and Analysis Develop the Simulation Capabilities Covering Both Preliminary Design and Detailed Analysis	Cross Discipline Software Coupling Software Interface Standards Module Development and Validation Development of Package Interconnections Image Chain Analysis	All	'92 - '08
Validation	Validation to the Appropriate Detail of the Components and End to End Accuracy of the Integrated Packages Via Specific Laboratory Experiments	Simulation Software Propagation Software Database Development Integrated Software Tool(s)	All	'92 - '08
Modeling Research	Research Into the Basic Techniques for Optical System Modeling	Scattered Light Scalar and Vector Diffraction Image Processing and Inversion Test Data Integration Cryogenic Heat Transfer Micro Mechanics Image Reconstruction	All	'92 - '08

INTEGRATED PACKAGE FOR INITIAL DESIGN

A. Technology Assessment

Space optical systems of the future will not have large monolithic circular optical elements. Future telescopes will have actively controlled, segmented, hexagonal apertures with ultra fast focal ratios. The optical elements of future telescopes, interferometers, and optical arrays will be precisely positioned by optical metrology systems rather than by heavy mechanical linkages. The traditional techniques for understanding and comparing the performance of initial optical system designs, techniques that are only extensions of Rayleigh's original work, cannot adequately describe the performance of these complex, non-circular, alignment sensitive systems. Accessible software tools are needed that allow initial designs to be characterized and compared quickly and inexpensively. The characterization must include the system's response to dynamic and thermal perturbations as well as static performance. In addition, these tools must be capable of providing the science instrument designers with an early and reasonably accurate understanding of the expected imaging and radiometric performance of the system.

Workstation based software tools for initial end-to-end design of complex optical systems are not available. The JPL Integrated Modeling of Optical Systems (IMOS) Project is attempting to fill this need, but the work is preliminary. Broad accessibility will require the use of common hardware and operating environments. Maintenance support and the existence of an active user group is also required. The system should be consistent with the standard software interfaces developed for detailed design so that the initial design can easily (transparently) be used as the starting point for the detailed design process.

B. Development Plan

The proposed development plan is to complete, document, and maintain the IMOS package

and encourage its wide distribution and use. The software architecture is highly modular, which encourages individual discipline modules from a wide variety of sources. A single institution with vested interest in the results, sophisticated software testing capability and configuration control discipline, should have the responsibility for the integration, validation, documentation, maintenance, and publication of the package. If the initial release of the package is widely accepted, commercialization of this activity may be possible. In any implementation, it must be closely linked to the ongoing validation program and it must be responsive to the user group.

INTERFACE DEVELOPMENT FOR DETAILED OPTIMIZATION

A. Technology Assessment

Existing software is available to carry out major portions of the modeling effort, but these software components are generally separate dedicated packages that address the geometrical design, physical optics analysis, structural analysis, and thermal effects separately. Since future missions will be dominated by the size and complexity of the optics, these separate areas must be tied together to permit system level evaluation of future design concepts.

Software packages (e.g., NASTRAN, ANSYS, SINDA, TRASYS, CODE V, GLAD, COMP, MATLAB, MATRIXX, EASY V, LINPACK, etc.) have been developed within several discrete technical disciplines for the separate analysis of the optical, structural, material, thermal, dynamic, science data analysis and control aspects of telescopes, spacecraft, and missions. Integration of existing software and the development of advanced codes are required to enable end-to-end simulation of system performance. A good start at producing software of this type has been taken under the U.S. Air Force funded Integrated System Modeling (ISM) effort and the ISM Lab tool. This effort is targeted at developing highly detailed subsystem designs whereas a design tool that allows rapid system design and analysis

within the context of global system performance is needed. Unfortunately, the Air Force has withdrawn their support of this program and further development will cease with the delivery of the final report to the Phillips Laboratories (contract monitor) in January 1992. Nevertheless, the ISM might be an excellent jumping off point in the development of an end-to-end modeling capability.

B. Development Plan

A summary of the tasks associated with this development area is presented in Table 38. Specific need dates and development time frames for this technology program are identified. The goal of this effort is to develop and maintain an end-to-end simulation capability that integrates optical, structural, control, and environmental design and analysis. This technology addresses the development of both the loosely linked detailed analysis capability and the tightly integrated initial design capability. The individual tasks that comprise this program follow.

The first development, *Cross Discipline Software*, is the development of a common "front end" for integrating cross discipline initial design software. For example, this would include the tight linking of optical software to NASTRAN node generators through compilation using a common output language.

In addition to front end software, *Coupling Software* is necessary such that a preliminary level of

design optimization can be carried out. This effort would provide for the design and development of software that would allow first order integrated optimization with the coupled design packages.

Concurrent with the other tasks, *Interface Standards* establishes a NASA wide board with industry and academic participation to develop interface standards for the various software simulation modules. The modules to be developed would be integrated into the detailed analysis package produced under this program.

Module Development and Validation are essential. This item includes creation and validation of each of the individual software packages that describe the components on an optical system. Validation against experimental data is critical. For example, thermal and mechanical stress tests would be carried out on a number of different lightweight mirror concepts, and the accuracy of prediction of response verified.

The last item implemented is the *Image Chain Analysis* effort. This is a full throughput image chain analysis (system verification) that includes all of the system and surface perturbations predicted by the various structural and environmental program modules. Taken as whole, this development program will provide the capabilities necessary for next century astrophysics missions.

Table 38. Required Interface Developments for Detailed Optimization

TECHNOLOGY	CURRENT TECHNOLOGY	PROGRAM GOALS	NEED DATES	TECH. DEV. TIME FRAME
Cross Discipline Software	Some Development Ongoing, But Very Limited ISM	"Front-End" Software to Integrate Cross Discipline Packages For Application to Initial Design	'97 Prelim '01 Update	'93 - '06
Coupling Software	Integrated Optimization Currently Not Possible	Develop Coupling Software	'98 Prelim '02 Update	'93 - '06
Interface Standards	ISM (Canceled by AF) Represents De Facto Standard	Develop Interface Standards for Existing and New Software Technology	'95 Prelim '97 Update	'93 - '06
Module Development and Validation	Incomplete	Create and Validate Program Modules Against Experimental Data	'98 Prelim '02 Update	'93 - '06
Image Chain Analysis	No General Purpose Capabilities Available	Develop Generic Capability by Adaptive Optics Modeling Example, i.e., Wavefront Sensing and Active Optics	'97 Prelim '02 Update	'93 - '06

VALIDATION

A. Technology Assessment

All modeling software that will be developed *must be validated as part of the development effort*. Software that cannot produce experimentally corroborated answers is useless. Since most of the advanced modeling capabilities required are very limited to non-existent, validation with experimental demonstrations or hardware has not occurred. In addition, the current materials and components database is inadequate and needs expansion. This is particularly important with respect to material micro properties.

B. Development Plan

Table 39 summarizes the development milestones necessary to meet the needs of the mission set. The individual tasks follow.

The validation of *Simulation Software* item is a comparison of new and existing software models against hardware data that is derived from tests and or actual mission operations. The accuracies of the simulations are evaluated and the respective models improved.

Validation of *Propagation Software* is also necessary. This effort validates the propagation software by comparing actual test data against the predicted propagation of wavefronts through sample systems, including polarization, diffraction and scattering effects. Laboratory systems would provide the data necessary for validation of the software predictions.

The establishment of a *Materials and Components Database* is essential. This effort establishes and maintains a materials and components database that has been verified by structural analysis. This database would contain qualified materials to be used for structural or optical components of systems. New materials and environmental conditions would be included in the database to eliminate the uncertainties presently existing in handbook data.

The final validation item, *Integrated Software Tools*, builds upon the experience gained with ground-based systems for extension to space-based systems of the future. Simulation software would be used to predict the effect of environment or dynamics upon the output of selected ground-based systems, and verified against observations. Once validated on ground-based systems, extension of the simulation capability to space-based systems could proceed.

Table 39. Required Developments In Validation

TECHNOLOGY	CURRENT TECHNOLOGY	PROGRAM GOALS	NEED DATES	TECH. DEV. TIME FRAME
Simulation Software	Very Limited	Validation of Simulation Software Against CSI or Equivalent Experimental Hardware	'98 Prelim '03 Update	'93 - '06
Propagation Software	Limited to GLAD and COMP	Validation of Propagation Software With Experimental Demos	'00 Prelim '04 Update	'93 - '06
Materials and Components Database	Inadequate	Establish and Maintain a Materials Database (Especially in Micro Properties)	'98 Prelim '02 Update	'93 - '06
Integrated Software Tools	Limited	Validate Simulation Capability of the Integrated Software Package With Ground Based Telescope Observations (e.g., Adaptive Optics)	'97 Prelim '00 Update	'93 - '01

MODELING RESEARCH

A. Technology Assessment

Research into the basic physics and analysis of the techniques needed to carry out optical modeling is required. Codes needed here have been developed in the past on an individual basis to solve specific problems/applications. As more problems have been solved, more software has been developed. Unfortunately, this method does not provide for the incorporation of these codes into a user friendly tool that can be used for subsequent application to other concepts. Polarization codes such as PMAP have been developed at the University of Arizona and the University of Alabama, Huntsville, under NASA sponsorship. Scalar diffraction codes that exist (GLAD V, formerly OASIS) have been very application specific with no existing integrated packages. COMP started within the DoD and has developed with Air Force funding at the University of Arizona and the Jet Propulsion Laboratory/California Institute of Technology. While most concepts covering optical propagation are well founded, there are some critical areas that need basic investigation for incorporation into an integrated modeling process. Examples within the discipline of optics are: (1) scattered light, (2) scalar and vector diffraction modeling for the optimization of submillimeter and far infrared imaging telescopes and for modeling of

instruments, (3) image formation and reconstruction from synthesized large apertures (fringe patterns), (4) integration of subsystem models, (5) thermal background noise modeling for optimization of infrared imaging telescopes, (6) nonlinear micro-mechanics, and (7) radiometric fidelity. It is important that NASA support this development as the length of time required to develop these codes negates the incentive within private industry to commit internal funding.

B. Development Plan

This research would produce a series of algorithms to be used in integrated optical modeling codes. Table 40 summarizes the techniques required with the individual tasks explained below.

Diffraction Modeling will provide for the development of a full vector analysis approach to diffraction imagery that can be used in polarization sensitive systems in all wavelength regions. The initial research would focus on the submillimeter regime. As the development program matures, extensions to shorter wavelength regimes would be implemented.

The *Scattered Light* research effort will extend the knowledge of scattered light generation, thermal emission, and polarization. This would be accomplished through a series of measurements at

various wavelengths on calibrated sample surfaces. The resulting data would be used to improve surface scattering theory and direct advanced modeling algorithm development.

Image Processing and Inversion research would build upon current algorithms and provide basic research for the extension of radio astronomy techniques to image processing and wavefront inversion at optical frequencies. It would also support the automation of wavefront reconstruction, phase retrieval, and optical prescription evaluation. Additionally, advanced research would be conducted on synthesized array imaging and image reconstruction. These program elements are necessary for full exploitation of current and novel techniques in future astrophysics systems.

Test Data Integration research would provide a methodology for integrating subsystem test

data within the overall system model for design verification.

The *Cryogenic Heat Transfer* research would refine the modeling of cryogenic heat transfer to permit high quality (accuracy) modeling of cooled optical components as well as detector focal planes. This effort would initially concentrate on the submillimeter and IR systems (liquid helium temperature heat transfer), with later extension to warmer systems.

The *Micro Mechanics* research activity involves a set of hardware and software experiments necessary for the modeling of nonlinear micromechanics in candidate materials. This effort would provide important information regarding the ability of materials to survive stresses, as well as to determine the long-term stability of candidate optical structures.

Table 40. Required Developments In Modeling Research

TECHNOLOGY	CURRENT TECHNOLOGY	PROGRAM GOALS	NEED DATES	TECH. DEV. TIME FRAME
Diffraction Modeling	EM/Polarization Not Used	Develop and Incorporate Advanced Scalar and Vector Diffraction Codes	'96 Prelim "00 Update	'93 - '02
Scattered Light	Sparse Database	Accepted Measurement Procedures Experimentally Verified Code	'95 Prelim '98 Update	'93 - '01
Image Processing and Inversion	Limited Experience	Automation of Retrieval and Wavefront Reconstruction Codes Application of Radio Astronomy Codes Synthesized Array Imaging and Reconstruction Research	'96 Prelim "00 Update	'93 - '01
Test Data Integration	Non Correlated Techniques	Design Verification	'97 Prelim "00 Update	'93 - '06
Cryogenic Heat Transfer	Very Limited	Develop Advanced Codes for Predicting/Simulating Cryogenic Heat Transfer	'97 Prelim "00 Update	'93 - '03
Micro Mechanics	Limited	Research and Development of Modeling Codes for Predictions of Micro Mechanics of Structural Features	'99 Prelim '04 Update	'93 - '06

